

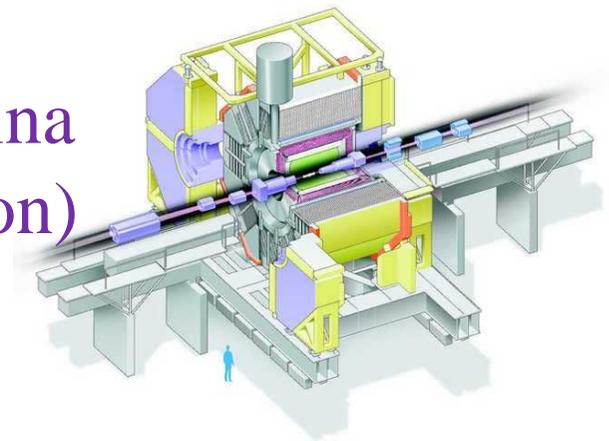


Study of $B \rightarrow X(3872) K \pi$ at Belle



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(for the Belle Collaboration)

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[‡] for Anu Bala (PU, Chandigarh)



Outline

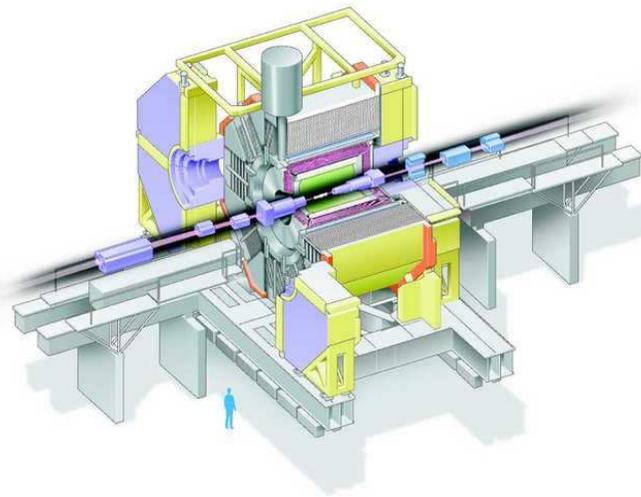
Published in Belle, PRD91, 051101 (R) (2015)

- ❖ Motivation
- ❖ Illustration with the large $B^0 \rightarrow \psi' K^+ \pi^-$ sample.
- ❖ Observation of $B^0 \rightarrow X(3872) K^+ \pi^-$ decay mode
- ❖ $\mathcal{B}(B^0 \rightarrow X(3872) K^+ \pi^-)$ measurement
- ❖ $M(K\pi)$ study
- ❖ Evidence of $B^+ \rightarrow X(3872) K_S^0 \pi^+$ decay mode
- ❖ Summary

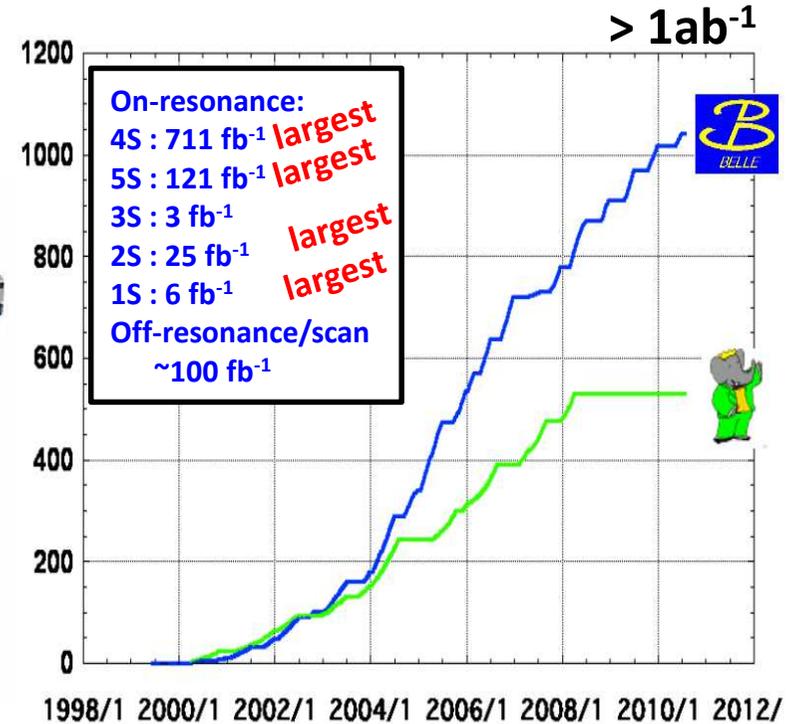
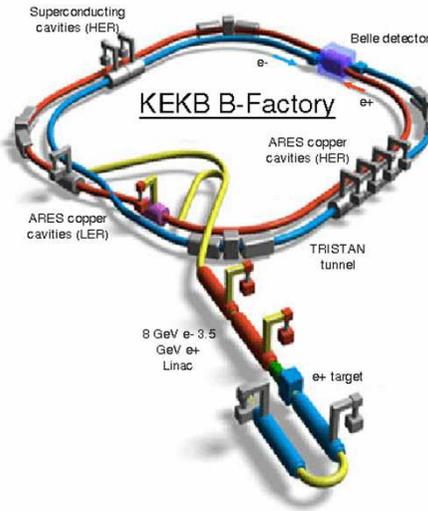
KEKB and Belle



General purpose detector



KEKB holds the world record of luminosity at colliders:
 $2.11 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$



- ❖ Belle started in 1999.
- ❖ Experiment designed for CP Violation measurement in $B^0 \rightarrow c\bar{c}K^0$
- ❖ Data taking stopped in June 2010.
- ❖ Belle recorded $\sim 772 \times 10^6$ $B\bar{B}$ pairs as final sample at $\Upsilon(4S)$ resonance.
- ❖ Excellent place to perform charmonium spectroscopy !

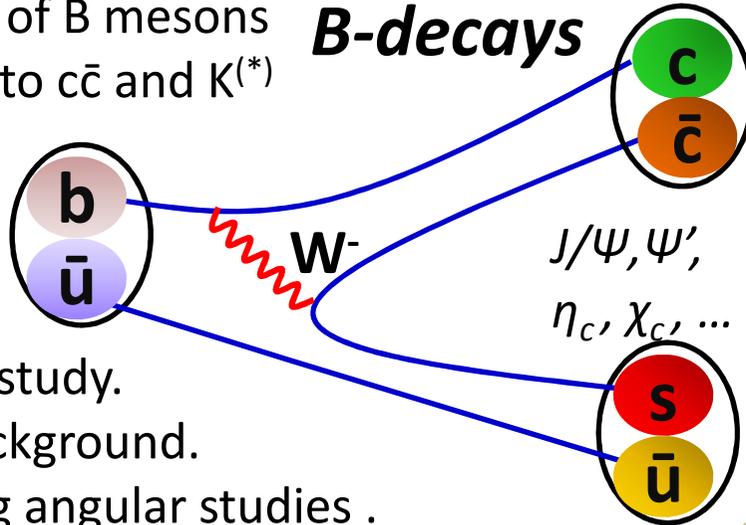


c \bar{c} production at Belle



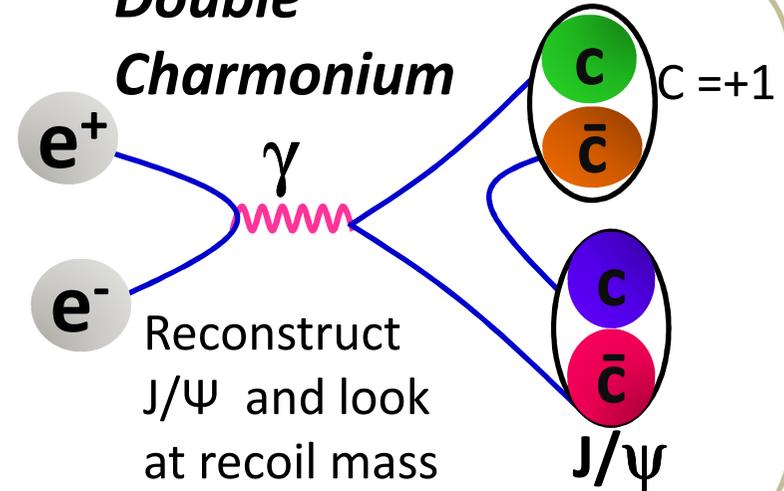
A few % of B mesons decay into c \bar{c} and K^(*)

B-decays



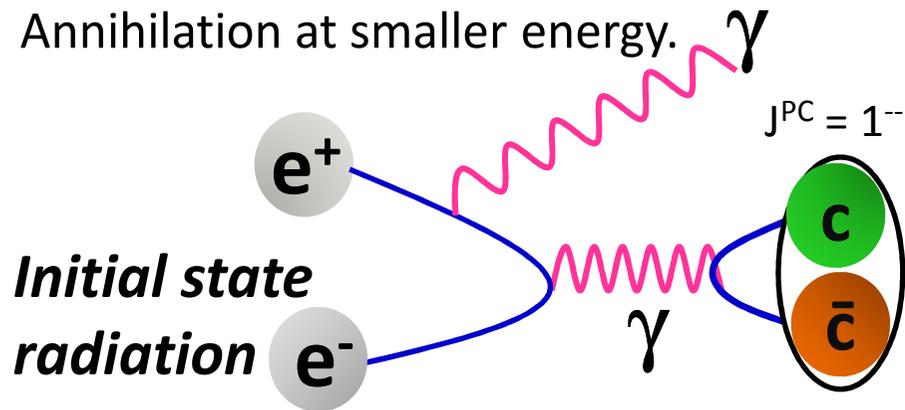
Easy to study.
Low background.
J^{PC} using angular studies .

Double Charmonium



Reconstruct J/ ψ and look at recoil mass

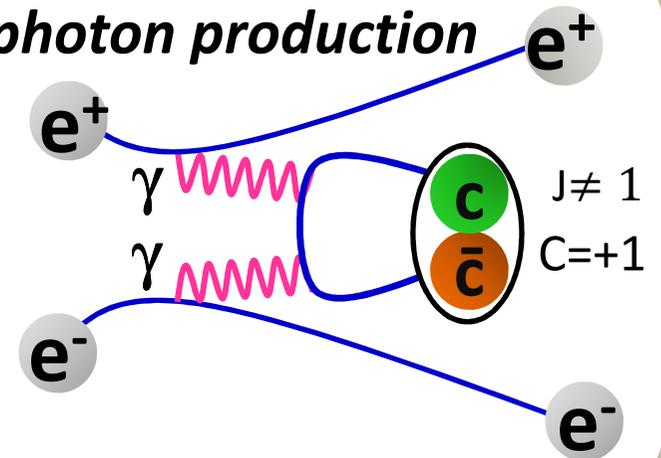
Annihilation at smaller energy.



Initial state radiation

Two-photon production

c \bar{c} states produced without additional hadrons.

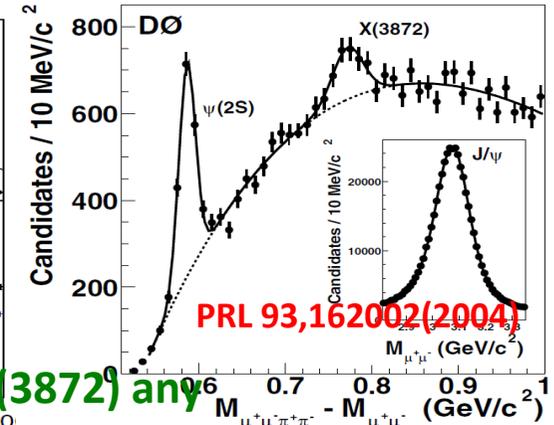
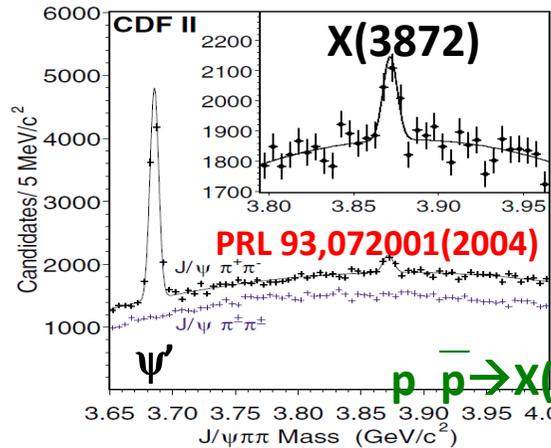
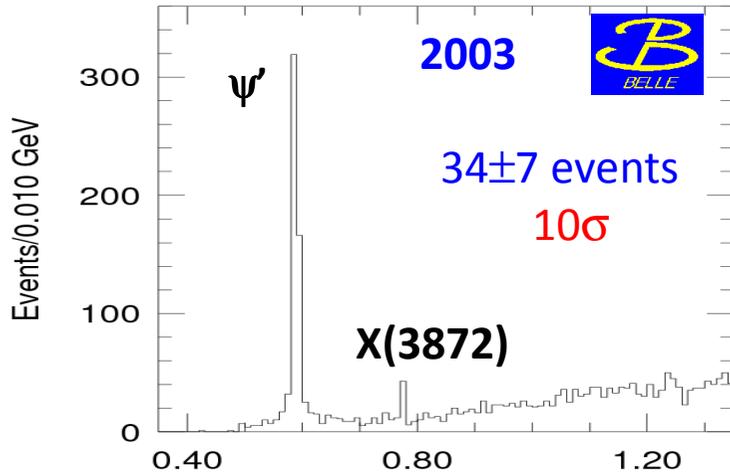


X(3872)



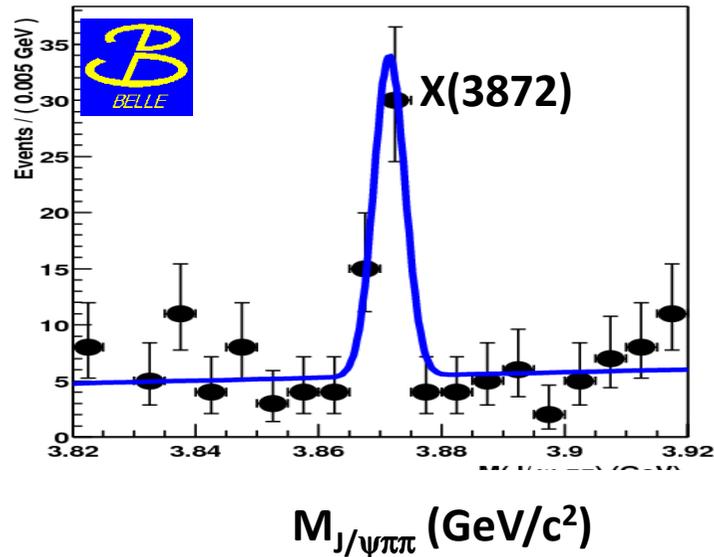
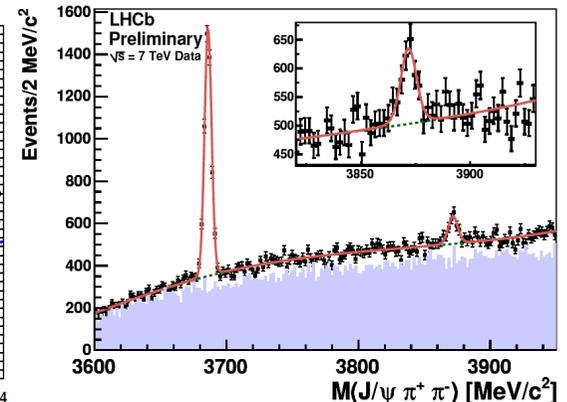
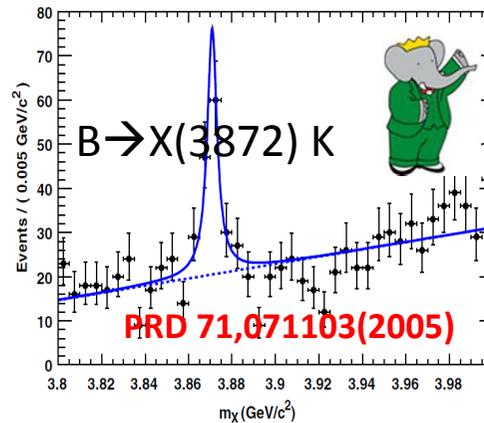
Discovered by Belle in $J/\psi\pi\pi$ decay mode

PRL 91,262001(2003)



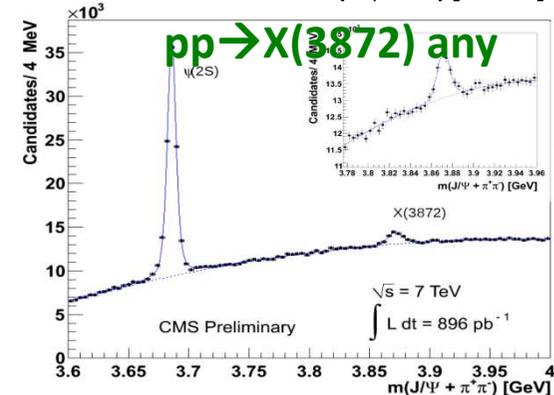
$p\bar{p} \rightarrow X(3872) \text{ any}$

$M_{J/\psi\pi\pi} - M_{J/\psi} \text{ (GeV/c}^2\text{)}$
 $B^+ \rightarrow X(3872) K^+$, $\Gamma < 2.5 \text{ MeV}$
 $X(3872) \rightarrow J/\psi\pi^+\pi^-$ (90%CL)



Confirmed by CDF, DO, BaBar, CMS and LHCb.

Current Properties
 $M = 3871.69 \pm 0.17 \text{ MeV}$
 $\Gamma < 1.2 \text{ MeV (90\%CL)}$
 $J^{PC} = 1^{++}$



$pp \rightarrow X(3872) \text{ any}$

Radiative and eXotic decay(s) of X(3872)



Belle found evidence for $X(3872) \rightarrow J/\psi \gamma$ in $B^+ \rightarrow X(3872) K^+$ [arXiv:0505037](#)

C=+1

Also seen by BaBar

BaBar also found signal in $X(3872) \rightarrow \psi' \gamma$ [PRD 83, 094009 \(2011\)](#)

$$\mathcal{B}(X(3872) \rightarrow \psi' \gamma) / \mathcal{B}(X(3872) \rightarrow J/\psi \gamma) = 3.5 \pm 1.4$$

[PRL 107, 091803 \(2011\)](#)

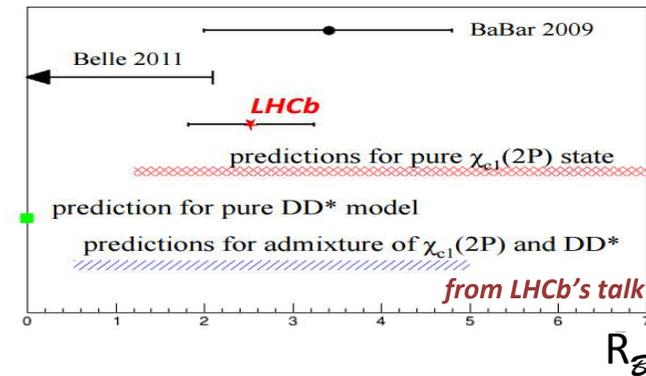
Update from Belle, established $X(3872) \rightarrow J/\psi \gamma$ with 5.5σ observation

$$\mathcal{B}(B^+ \rightarrow XK^+) \times \mathcal{B}(X \rightarrow J/\psi \gamma) = (1.78 \pm 0.46 \pm 0.12) \times 10^{-6}$$

However, no evidence for $X(3872) \rightarrow \Psi' \gamma$

Recently, LHCb has confirmed $X(3872) \rightarrow \Psi' \gamma$, provided more precise measurement : consistent with Belle and BaBar.

[NPB 886, 665 \(2014\)](#)



Belle & BaBar both observe $X(3872) \rightarrow D^{*0} \bar{D}^0$ but they got slight shift in mass

recent Mass $\rightarrow 3872.9^{+0.6}_{-0.4} {}^{+0.4}_{-0.5}$ MeV/c² [PRL 97,162002 \(2006\)](#), [PRD 81, 031103 \(2010\)](#)

Mass $\rightarrow 3875.1^{+0.7}_{-0.5} \pm 0.5$ MeV/c² [PRD 77,011102 \(2008\)](#)

These decays along with negative search of $\chi_{c1}' \rightarrow \chi_{c1} \pi^+ \pi^-$ suggest :
 $X(3872)$ to be an admixture of $D\bar{D}^*$ molecule and χ_{c1}' state*.

See my previous talk



Study of $B \rightarrow X(3872) K\pi$

- ❖ Attempt to understand the *production* of $X(3872)$ in $B \rightarrow X(3872) K\pi$, in comparison to normal charmonium state.
- ❖ First study was done by Belle using 605 fb^{-1} arXiv:0809.1224, BELLE-CONF-0849
 - ✓ Saw signal of $B^0 \rightarrow X(3872) K^+ \pi^-$.
 - ✓ $\mathcal{B}(B^0 \rightarrow X(3872) K^+ \pi^-) \mathcal{B}(X(3872) \rightarrow J/\psi \pi \pi) = (8.1 \pm 2.0_{-1.4}^{+1.1}) \times 10^{-6}$
 - ✓ $\mathcal{B}(B \rightarrow X(3872) K^{*0}) \mathcal{B}(X(3872) \rightarrow J/\psi \pi \pi) < 3.4 \times 10^{-6}$ (90% CL)
 - ✓ Non-resonant contribution dominates, unlike other $c\bar{c}$ states.
- ❖ With full data sample (711 fb^{-1}) and reprocessed data, one expects more sensitivity to the study.
 - Improved analysis technique.
- ❖ Further, $B^+ \rightarrow X(3872) K_S^0 \pi^+$ is also studied in an attempt to increase the statistics.
- ❖ Exploit $B \rightarrow \psi' K\pi$ as calibration mode to train and calibrate $B \rightarrow X(3872) K\pi$ decay mode.

Selection criteria



- $B^0 \rightarrow \psi' (K^+\pi^-)$ and $B^0 \rightarrow X(3872) (K^+\pi^-)$ selection criteria
- Beam-constraint mass

$$M_{bc} = \sqrt{E_{beam}^2 - p_B^2} > 5.27 \text{ GeV}/c^2$$

- To avoid combinatorial background from $\pi^+ \pi^-$
 - $M_{\pi^+ \pi^-} > (M_{(\pi^+ \pi^- J/\psi)} - (m_{J/\psi} + 0.2 \text{ GeV}/c^2))$
- Fit was performed in 2-D using ΔE & $M_{J/\psi\pi\pi}$
 - $-0.1 \text{ GeV} < \Delta E < 0.1 \text{ GeV}$
 - $3.64 < M_{J/\psi\pi\pi} < 3.74 \text{ GeV}/c^2$ for $B^0 \rightarrow \psi' (K^+\pi^-)$
 - $3.82 < M_{J/\psi\pi\pi} < 3.92 \text{ GeV}/c^2$ for $B^0 \rightarrow X(3872) (K^+\pi^-)$

Based upon above selection cuts, reconstruction efficiency from MC is:

Decay Mode	Weighted Signal Efficiency (%)
$B^0 \rightarrow X(3872) (K^+\pi^-)$	16.0
$B^+ \rightarrow X(3872) (K_S^0\pi^+)$	10.3



Signal Extraction

For signal extraction :

- 2-D fit to ΔE & $M_{J/\psi\pi\pi}$ to observe $B \rightarrow X(3872) (K\pi)$ decay mode.

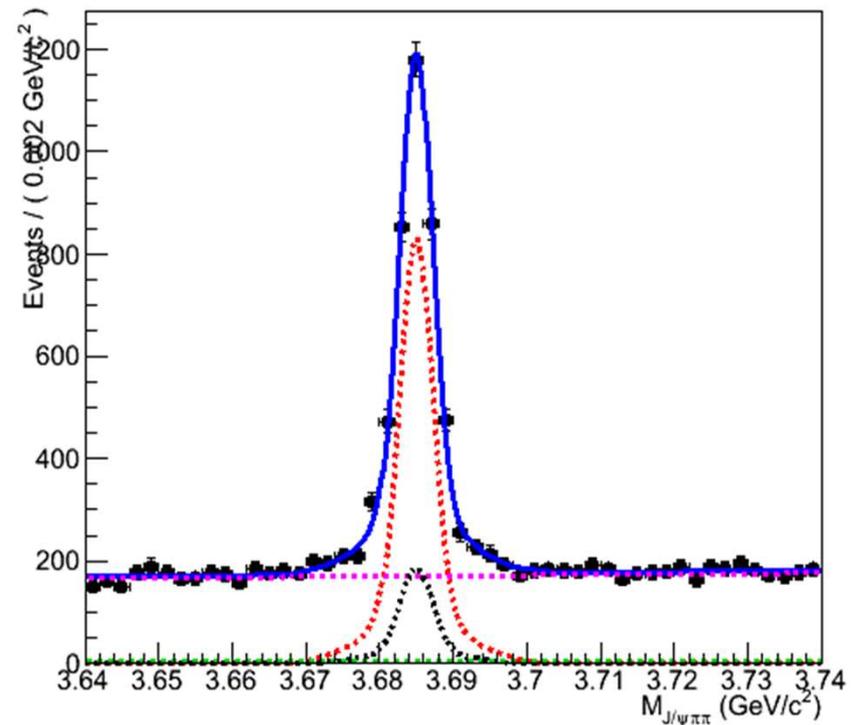
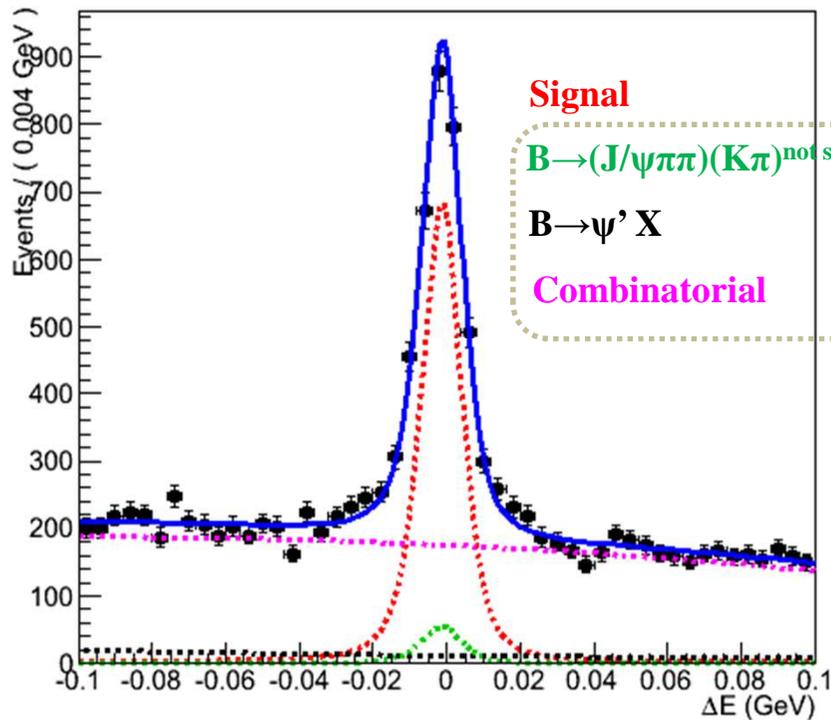
- Background estimated from :
 - ✓ Large $B \rightarrow J/\psi X$ signal MC (x 100 times data)
 - ✓ Non- J/ψ background estimated using J/ψ mass sidebands.
 - ✓ 89fb^{-1} off resonance data collected at 60 MeV below $\Upsilon(4S)$.

- Major background comes from $B \rightarrow J/\psi X$ processes.

- The procedure is first tested with $B^0 \rightarrow \psi' (K^+\pi^-)$:
 - Same final state
 - Larger statistics (~ 2600 events).

2-D Fit (ΔE and $M_{J/\psi\pi\pi}$)

$B^0 \rightarrow \psi' K^+ \pi^-$ decay mode



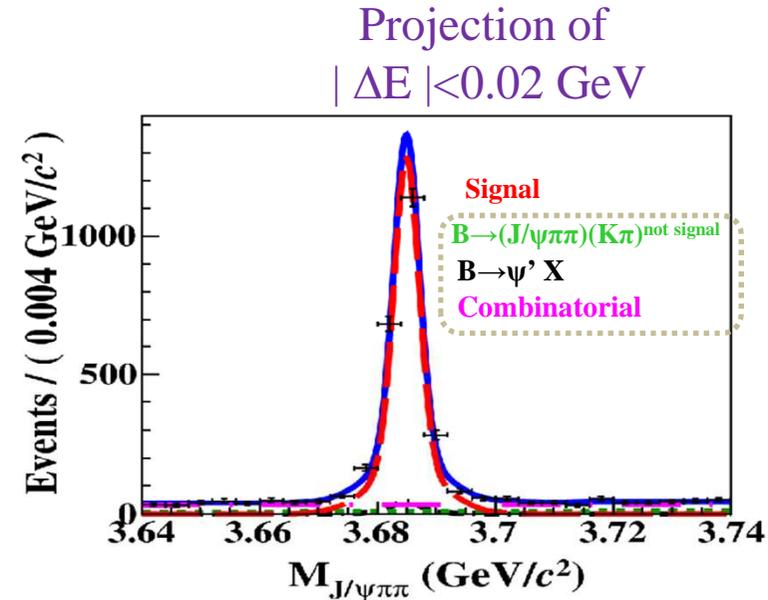
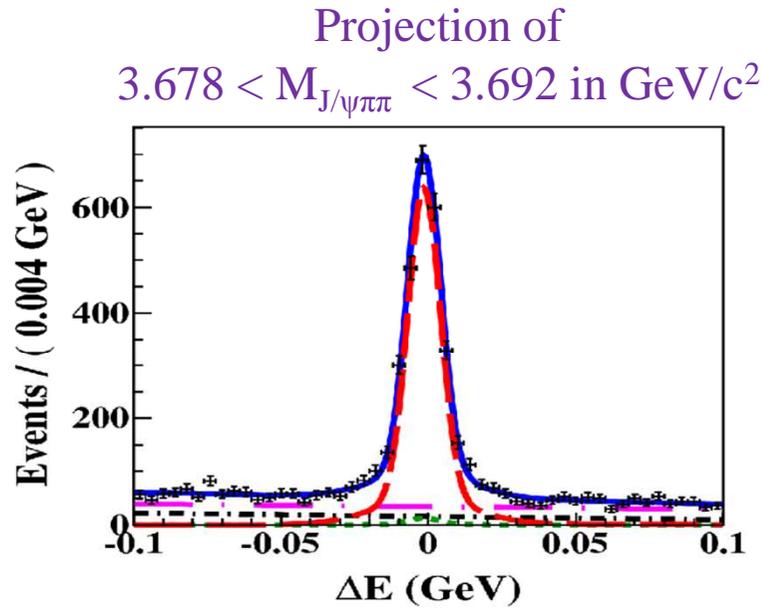
Peaking background

- Same final state, $B \rightarrow (J/\psi\pi\pi)(K\pi)$, peaks at ΔE
- Decay modes of the type $B \rightarrow \psi' X$, peaks at $M_{J/\psi\pi\pi}$

Tested our fitter with toys and no bias was seen.

Control sample in data

$B^0 \rightarrow \psi' K^+ \pi^-$ decay mode



$$\mathcal{B}(B^0 \rightarrow \psi' K^+ \pi^-) = (5.79 \pm 0.14) \times 10^{-4}$$

Belle latest measurement[‡]: $(5.80 \pm 0.16 \pm 0.32) \times 10^{-4}$ PRD 88, 074026 (2013)

[‡] This \mathcal{B} includes $\psi' \rightarrow J/\psi\pi\pi$ and $\psi' \rightarrow ll$ and is estimated using full amplitude fit result.

- In our measurement, no interference and $Z(4430)^+ \rightarrow \psi' \pi$ component is taken into account.
- This is just an illustration for $B \rightarrow X(3872) K\pi$ study:
 - one expects 100-150 signal events

$B^0 \rightarrow \psi' K\pi$ decay mode is used to calibrate our PDF resolutions.

Different components of $M(K\pi)$ system



- ❖ Our interest lies in understanding the decay dynamics of $X(3872) K\pi$
 - Study of $M(K\pi)$ becomes a straight forward choice.
- ❖ Measured $\mathcal{B}(B^0 \rightarrow \psi' K^+ \pi^-)$ includes all possible components:
 - $K^*(892)$, $K_2^*(1430)$ and $(K^+ \pi^-)_{NR}$, etc ..
- ❖ Interesting to separate the resonant and non-resonant components
 - Fit to $M(K\pi)$

We fit ΔE & $M_{J/\psi\pi\pi}$ in bins of $M(K\pi)$ to obtain background subtracted $M(K\pi)$ distribution

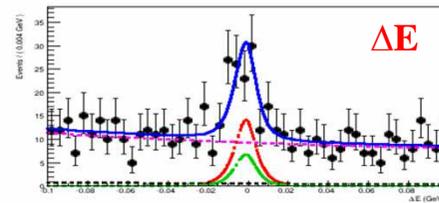
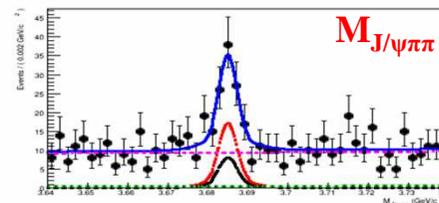
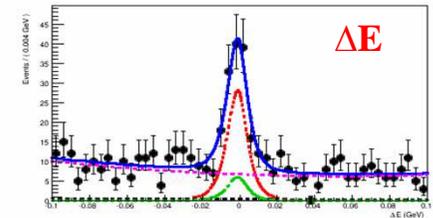
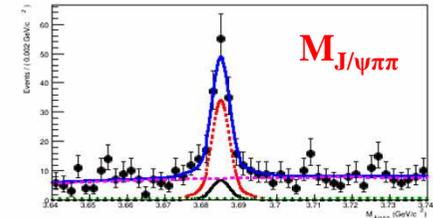
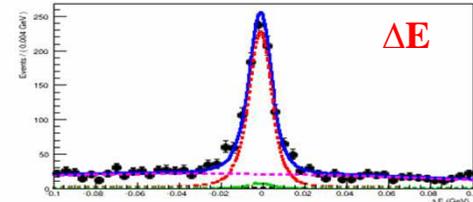
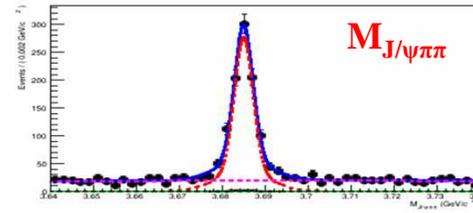
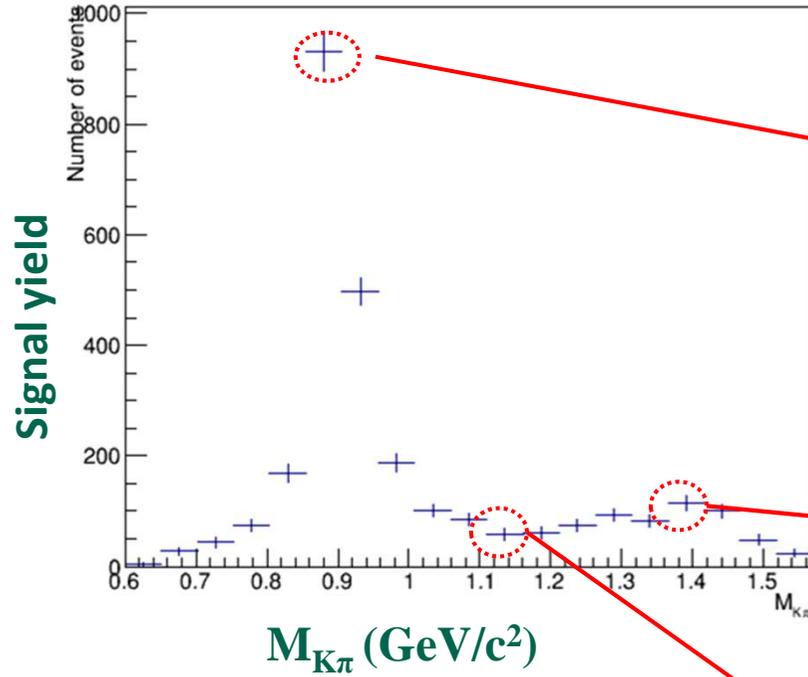
Fit the resultant $M(K\pi)$ distribution to extract the resonant (K^*) and non-resonant (PHSP) components.

50 MeV/c^2 wide for ψ' and 100 MeV/c^2 wide for $X(3872)$

Yield from 2-D fit with 50 MeV wide bins of



$M_{K\pi}$



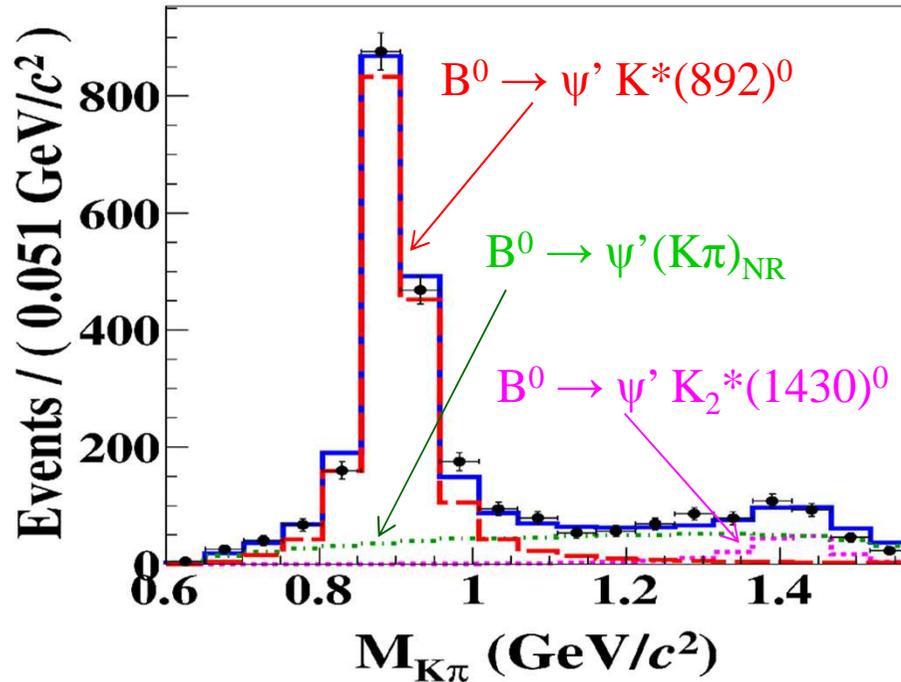
Yields and Errors provided by 2-D fit in each bin of $M_{K\pi}$



$B^0 \rightarrow \psi' K^+ \pi^-$

Fit to background subtracted $M(K\pi)$

PRD91, 051101 (R) (2015)



- 1D binned fit
- Histogram PDF from signal MC
- Toy studies show no significant bias in fitter

$$\frac{B(B^0 \rightarrow \psi' K^*(892)^0) \times B(K^*(892)^0 \rightarrow K^+ \pi^-)}{B(B^0 \rightarrow \psi' K^+ \pi^-)} = 0.68 \pm 0.01 (\text{stat.})$$

$B \rightarrow \psi' K^*(892)$: largest contribution over the rest

$$\begin{aligned} \mathcal{B}(B^0 \rightarrow \psi' K^*(892)^0) &= (5.88 \pm 0.18) \times 10^{-4} \quad [\text{Measured}] \quad (\text{stat. only}) \\ &= (6.1 \pm 0.5) \times 10^{-4} \quad [\text{PDG}] \\ &= (5.55^{+0.22+0.41}_{-0.23-0.84}) \times 10^{-4} \quad [\text{Belle latest measurement}] \end{aligned}$$

PRD 88, 074026 (2013)

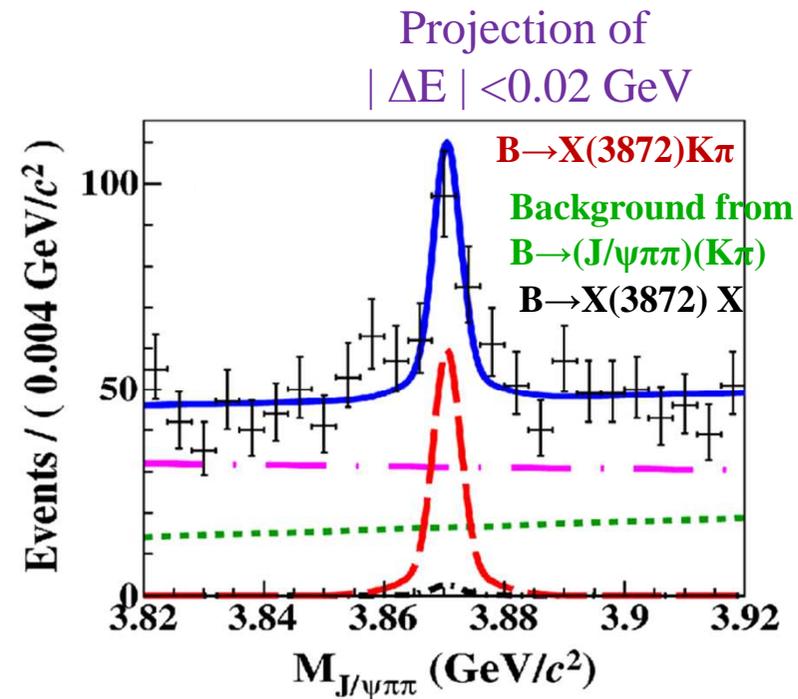
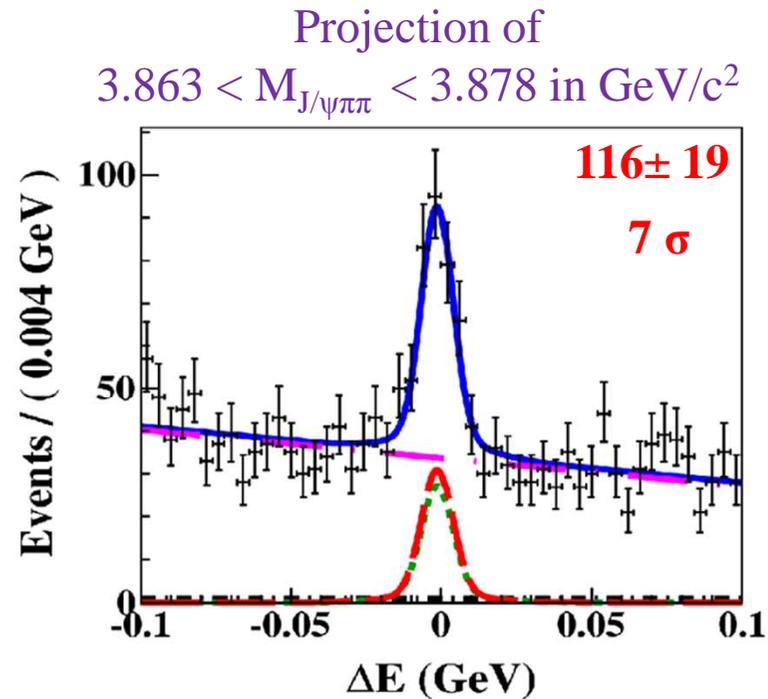
In spite of a simple fit, our results are compatible with previously measured results.



$B^0 \rightarrow X(3872) K^+ \pi^-$ decay mode study

2-D ($\Delta E - M_{J/\psi\pi\pi}$) Fit to data for $B^0 \rightarrow X(3872) K^+ \pi^-$ decay mode

PRD91, 051101 (R) (2015)



A clear signal peak is observed for $B^0 \rightarrow X(3872) K^+ \pi^-$ decay mode

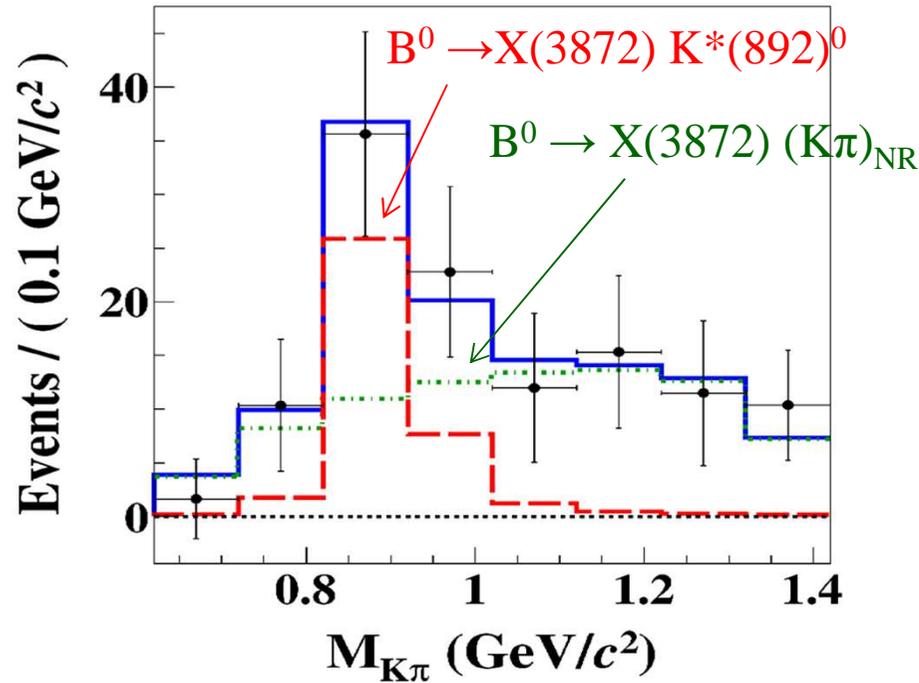
$$\mathcal{B}(B^0 \rightarrow X(3872) K^+ \pi^-) \times \mathcal{B}(X(3872) \rightarrow J/\psi \pi^+ \pi^-) = (7.91 \pm 1.29 \pm 0.43) \times 10^{-6}$$

$B^0 \rightarrow X(3872)K^+\pi^-$

Fit to background subtracted $M(K\pi)$



PRD91, 051101 (R) (2015)



- 1D binned fit
- Histogram PDF from signal MC
- Toy studies show no significant bias in fitter
- ❖ Upper bound on $M(K\pi)$ due to the kinematics is $1.41 \text{ GeV}/c^2$
 - Excluded $K_2^*(1430)$ in this fit

$$\frac{B(B^0 \rightarrow X(3872)K^*(892)^0) \times B(K^*(892)^0 \rightarrow K^+\pi^-)}{B(B^0 \rightarrow X(3872)K^+\pi^-)} = 0.34 \pm 0.09(\text{stat.}) \pm 0.02(\text{syst.})$$

while

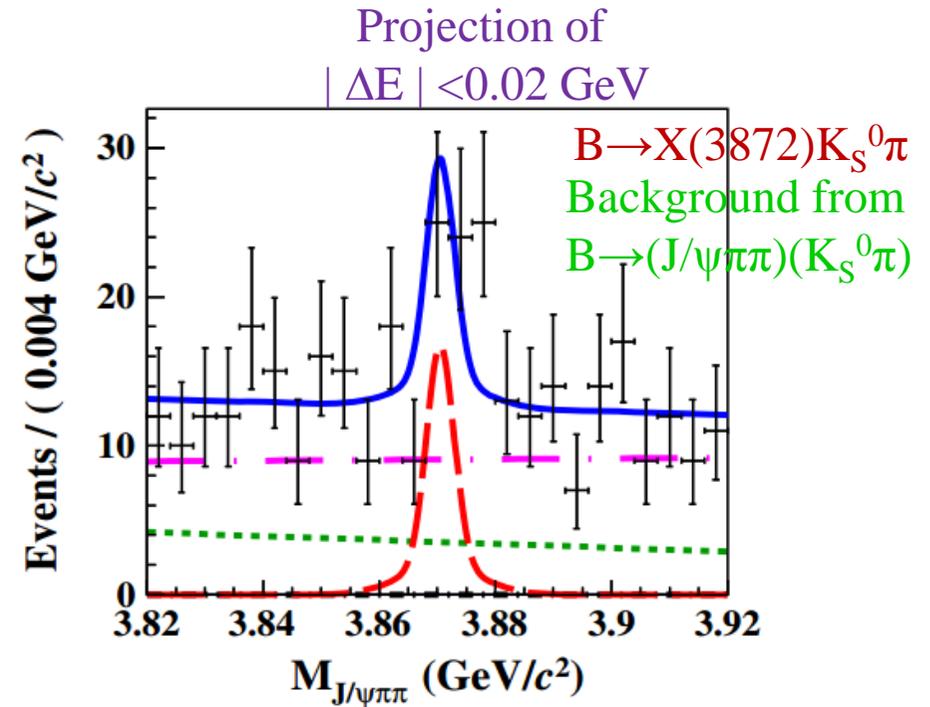
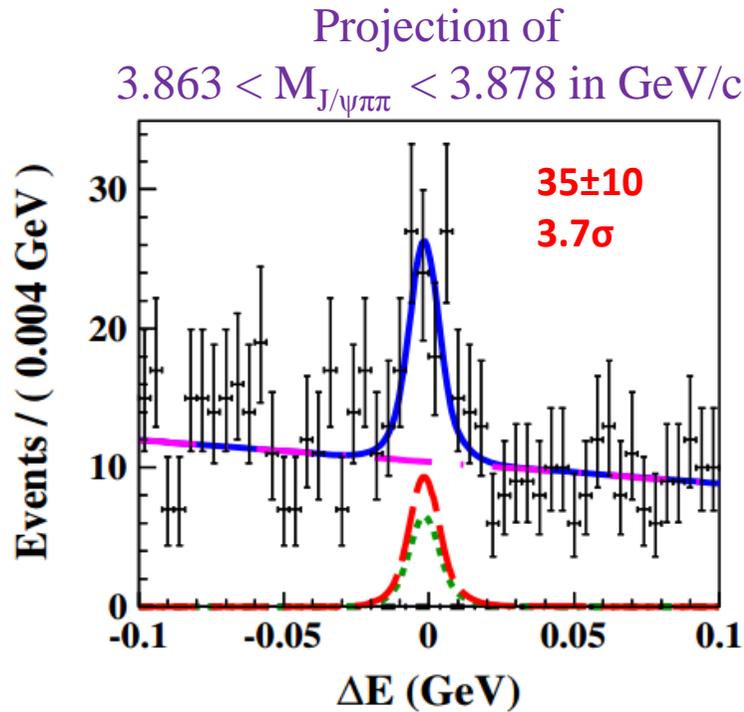
$$\frac{B(B^0 \rightarrow \psi'K^*(892)^0) \times B(K^*(892)^0 \rightarrow K^+\pi^-)}{B(B^0 \rightarrow \psi'K^+\pi^-)} = 0.68 \pm 0.01(\text{stat.})$$

❖ Here $K^*(892)^0$ has less contribution as compared to the level seen in Ψ' .

$B^+ \rightarrow X(3872)K_S^0\pi^+$

2D UML fit

$B^+ \rightarrow \psi' K_S^0 \pi^+$ decay mode is used as calibration mode.



First evidence for $B^+ \rightarrow X(3872)K_S^0\pi^+$ decay mode

$$\mathcal{B}(B^+ \rightarrow X(3872)K^0\pi^+) \times \mathcal{B}(X(3872) \rightarrow J/\psi\pi^+\pi^-) = (10.61 \pm 3.04 \text{ (stat)} \pm 0.85 \text{ (syst)}) \times 10^{-6}$$

In absence of sufficient statistics, we didn't study its $M(K\pi)$ distribution.

Summary

❖ Clear observation of $B^0 \rightarrow X(3872)K^+\pi^-$ decay mode using Belle full data sample.

$$\text{BR}(B^0 \rightarrow X(3872)K^+\pi^-) \times \text{BR}(X(3872) \rightarrow J/\psi\pi\pi) = (7.91 \pm 1.29 \pm 0.43) \times 10^{-6}$$

116±19 signal events with 7σ

❖ First evidence of $B^+ \rightarrow X(3872)K_S^0\pi^+$ decay mode

$$\text{BR}(B^+ \rightarrow X(3872)K_S^0\pi^+) \times \text{BR}(X(3872) \rightarrow J/\psi\pi\pi) = (10.61 \pm 3.04 \pm 0.85) \times 10^{-6}$$

35±10 signal events with 3.7σ

❖ Studied production dynamics using $M(K\pi)$ system.

➤ $K^*(892)^0$ component in $(K\pi)$ system in $X(3872)$ does not dominate, is in marked contrast to Ψ' case.

❖ Most probable :

○ $X(3872)$ to be an admixture of $D\bar{D}^*$ molecule and χ_{c1}' state*.



Thank you

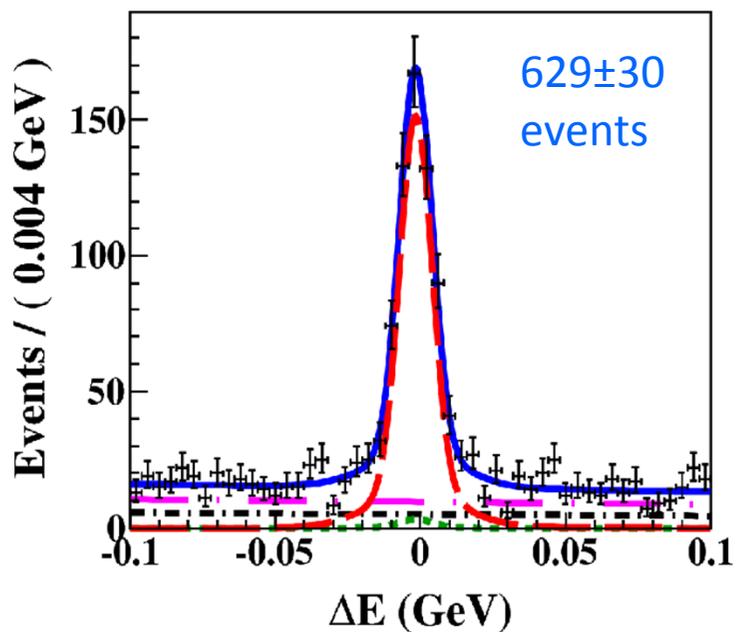


Backup

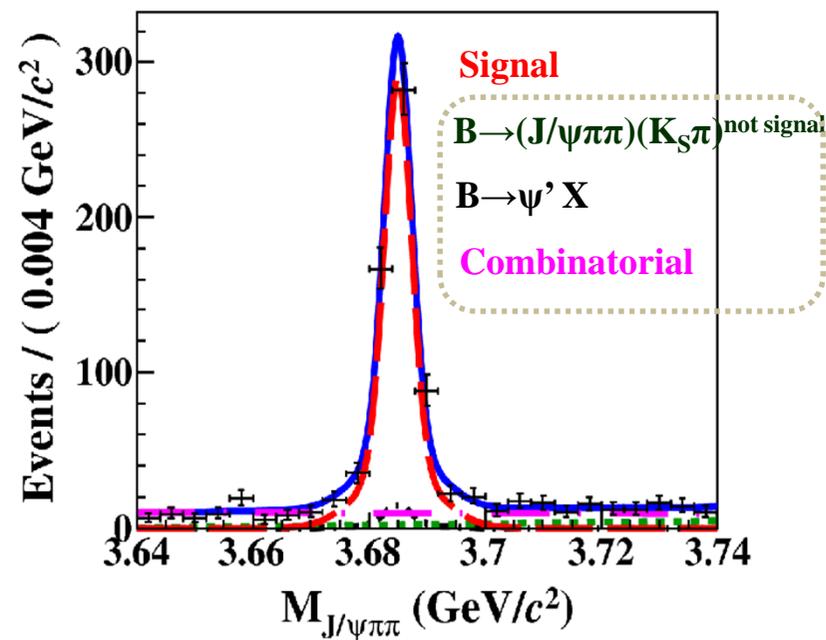
$B^+ \rightarrow \psi' K_S^0 \pi^+$

2D UML fit

Projection of
 $3.678 < M_{J/\psi\pi\pi} < 3.692$ in GeV/c^2



Projection of
 $|\Delta E| < 0.02$ GeV



$$\mathcal{B}(B^+ \rightarrow \psi' K^0 \pi^+) = (6.00 \pm 0.28(\text{stat})) \times 10^{-4}$$

$$\text{World Average: } (5.88 \pm 0.34) \times 10^{-4}$$

Results are compatible with previously measured results.

